This comprehensive account of the growing challenge of transportation hazards to health and safety strongly emphasizes the responsibility of both physician and public health officer in preventing accidental trauma.

Health and Safety in Transportation

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THE ASSURANCE of health and safety in transportation has become one of the basic needs in modern life. In certain areas of the world, safety in transit is assuming even greater importance than problems relating to food, shelter, and clothing. In the United States, for example, extensive mechanization of the environment, diverse industrial procedures, and increasing use of transport vehicles have resulted in new threats to the well-being of large sections of the population.

The important role played by human variables in causing accidents brings the control of accidents within the province of preventive medicine and public health. The physician and the public health officer, with their broad training in the biological sciences, are especially qualified to improve safety in industry, in the home, and in various forms of transportation.

Efforts in the control of accidents can be strengthened by the application of epidemiological techniques. The methods which have been used so effectively in the control of infectious disease can be broadened to prevent injuries, especially on the highway and in the air (*1*). Since most accidents have multiple causes, the interactions between the "host" (driver, pilot, or operator), the "agent" (vehicle, plane, and equipment), and the "environment" are important considerations in attempts at control. While the host factors are of particular interest to physicians, they must be viewed in their relationships to the agent and the environment for an adequate understanding of accident causation (*2*).

Because human variables are especially important in causing accidents, the physician or the public health officer has a direct responsibility in the prevention of injury. Moreover, since memory operates most effectively when reinforced by emotion, the physician is in an especially favorable position to teach while treating and to indoctrinate patients with the principles of accident prevention. It is thus of great importance for the physician to take the initiative in identifying the causes of accidents in order to institute preventive procedures (*3*).

Current approaches to the control of accidents may possibly be reaching the limits of their effectiveness. The next significant advances in safety may result from a combined approach which includes the engineering and

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Dr. McFarland, who is professor of environmental health and safety at the Harvard School of Public Health and director of the Guggenheim Center for Aviation Health and Safety, is a prolific author on the subject of transportation safety. *The paper was delivered in essentially the same form before the American College of Preventive Medicine in Cleveland, Ohio, on November 13, 1957. Many of the studies reported were sponsored by the Commission on Accidental Trauma of the Armed Forces Epidemiological Board, Department of Defense, and supported in part by funds from the Office of the Surgeon General, Department of the Army.*

biological sciences. This collaboration is not new in medicine, and such an approach has been the basis of many important developments. For example, the control of malaria was achieved by cooperation between the entomologist, the sanitary engineer, and other specialists. The physiologist, the psychologist, the anthropologist, the engineer, and the physician can similarly cooperate to obtain basic data in order to achieve improved prevention of motor vehicle accidents (*4*).

Transportation Facts and Figures

A few examples of the extent to which passenger transportation has increased in modern times show the magnitude of the problem.

In 1956, buses, automobiles, taxis, and trucks, operated by 77 million licensed drivers, traveled some 630 billion miles on the highways in the United States. Drivers and passengers in automobiles and taxis alone accounted for 970 billion passenger-miles of travel; 51½ billion passenger-miles were recorded in intercity bus operations.

In aviation the volume and speed of travel have been increasing very rapidly. During the first 24 years of the air transportation industry, that is, up to 1950, 100 million revenue passengers were carried by scheduled domestic and international carriers in the United States. By 1957, 349 million revenue passengers had been carried. The number of revenue passengers on airlines of the United States in 1956 was about 46 million. These represented about 70 percent of the total world volume of 68 million revenue passengers on airlines. In 1956 for the first time more passengers were carried to Europe by air than by ocean liner, and 68 percent of all passenger traffic between the United States and other nations was by air. Helicopter scheduled airlines were nonexistent 5 years ago. In 1957, this new type of service carried 152,000 passengers (*5*, *6*).

The transition from piston engines to jet propulsion will impose new and interesting problems in the next few years. Approximately 350 jet transports are now on order. These planes will carry as many as 140 passengers each at a cruising speed of approximately 600 miles per hour.

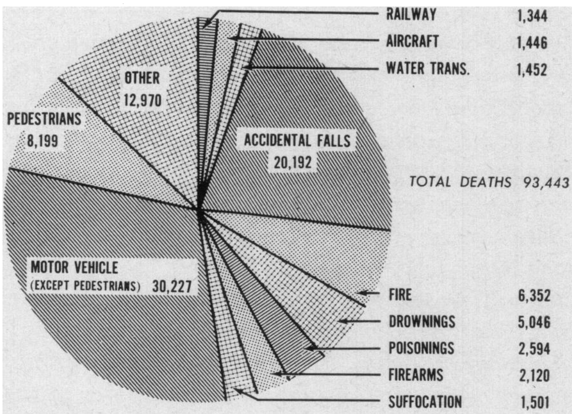
The number of revenue passengers using the railways exceeds 400 million per year, excluding commuters. Also, in 1956, more than 9 billion separate fares were paid by local transit riders.

It is now apparent that almost everyone uses some mode of travel or another, not once, but many times during the course of the year. The exposure of our populations to travel hazards has reached enormous proportions both in relation to accidental injury and the threat of exposure to certain diseases.

The frequency of accidents now presents a major problem. Each year approximately 95,000 persons are killed in various kinds of accidents in the United States (fig. 1). About 350,000 others receive permanently disabling injuries, and temporary disabilities severe enough to keep them away from work for at least a day are incurred by 9½ million persons. These accidents occur mainly in the home, on the job, and during transit. Accidents in various forms of transportation, particularly on the highway, have reached epidemic proportions. Since the invention of the automobile there have been more than a million fatalities in motor vehicle accidents in the United States; in 1957, highway accidents accounted for 41 percent of all accidental deaths. The annual direct costs of traffic accidents approximate 2 percent of the national income (*7*, *8*).

Fatal accidents involving persons under 35 years of age formed a large proportion of the

Figure 1. Accidental deaths in the United States during 1955.



SOURCE: Reference 7.

total deaths in highway accidents. This implies an enormous drain on the productive resources of the country. Accidents are the leading cause of death for persons between 1 and 34. They are exceeded only by heart disease and cancer for those between 35 and 44 years of age (*9*).

In the armed services, accidental trauma is now a major problem. During World War II the United States Army reported more deaths among its soldiers caused by accidents than by disease for the first time in its history. In the Korean conflict more than half of the hospitalized casualties resulted from accidents rather than from enemy action. Of these, 70 percent were incurred in motor vehicle accidents (*1*). The frequency of motor vehicle accidents in all three branches of the Armed Forces has become very serious, and accidents now exceed upper respiratory infections and rank first as the leading cause of man-days lost. Motor vehicle accidents account for about 2,100 fatalities of servicemen each year, a large majority occurring while personnel are off duty (*10*).

The integration of motor vehicles into our way of life has become very costly in fatalities, injuries, and damaged equipment. In spite of the enormous increase in volume of highway traffic, there has been a significant decrease in accident rates during the past 25 years. For example, in 1957 the fatality rate per 100 million miles of travel was only 5.9, in comparison with the rate of approximately 15 about 20 years ago. Nevertheless, the actual number of persons killed or disabled and resulting costs to the Nation's economy have increased from year to year with only a few exceptions apart from the period of restricted travel during World War II. In 1957 there were approximately 38,500 deaths and 1,350,000 injuries disabling beyond the day of the accident (*7*). According to present trends, it is estimated that 1 of every 10 persons in the country will be injured or killed in a traffic accident during the next 15 years (*8*).

The safety record of scheduled airlines in the United States is an enviable one in relation to the exposure. Only 154 fatalities were reported for 1956, with the 128 deaths in the Grand Canyon accident accounting for approximately five-sixths of this total (*5*). In 1957, there were 31 deaths. Business flying is reasonably safe, but private flying has a relatively poor record. There were 655 fatalities in 1956 in 3,411 accidents among 65,000 business and private planes. Thus, 1 in about every 19 of these airplanes was involved in an accident. Crop dusting by airplanes, of great importance to both public health and agriculture, is also hazardous. Military flying obviously involves increased hazards. However, in United States naval aviation there is now only about one fatality per day. For example, in 1956, there were 413 deaths attributable to aviation accidents (*11*). In the U. S. Air Force, with its far more extensive operations, deaths have been reduced to about three per flying day (*12*). In 1955, there were 825 fatalities.

To determine precisely the relative safety of different kinds of transportation is impossible because of the lack of a satisfactory common denominator for a valid comparison. The nature and frequency of the hazards encountered differ greatly among the various forms of transport, as does the number of passengers exposed to danger of injury in the different types of vehicles (*13*).

At present, death and injury rates per 100 million passenger-miles are used in estimating the safety of travel, and, on this basis, table 1 shows the accident death rates in passenger transportation (*5*, *7*). While deaths per 100 million passenger-miles is not a wholly satisfactory basis for this comparison, it appears that on the whole buses and trains have the lowest rates. Those for automobiles and taxis are much higher, and air transportation occupies a

Table 1. Accidental deaths of passengers per 100 million passenger-miles in United States transportation, 1947–56

Type of carrier	1947–51 average	1952	1953–55 average	1956
Scheduled air transport:				
Domestic	1. 6	0. 37	0. 49	0. 64
International	1. 1	2. 98	. 03	. 17
Railroad passenger trains	. 27	. 04	. 10	. 20
Intercity buses	. 19	. 16	. 14	. 16
Automobiles and taxis	2. 2	2. 8	2. 7	2. 7

Source: References 5 and 7.

middle position, slightly above those for trains and buses. Actually, the accident frequency rates for air transportation are quite low; the fatality rates reflect chiefly the fact that there are few survivors in the major accidents.

Epidemiological Approach

A basic step in the application of the epidemiological approach is determining the fundamental physical, physiological, and psychological characteristics of the host. When these data are correlated with the characteristics of the agent (vehicles and equipment) under specific environmental conditions, the resulting information will shed light on the causes of accidents and aid in developing preventive measures. To obtain this kind of information experimental and clinical studies, epidemiological surveys, and careful statistical analysis are required (*3*).

An epidemiological approach to highway safety in the armed services was applied in a recent study sponsored by the Commission on Accidental Trauma of the Armed Forces Epidemiological Board. About 88 percent of highway accidents in the Navy and Marine Corps occur while the personnel are off duty. The epidemiological method was used to study this problem at a major Marine Corps base.

It was previously supposed that the main problem concerned fatal accidents during weekend periods on considerably long automobile trips. The study showed, however, that 96 percent of the accidents occurred within a 50-mile radius of the base, and 71 percent within 10 miles. The greatest percentage of accidents occurred between 6 p.m. and midnight, that is, during the evening recreation period. The analysis identified the young, unmarried enlisted men of low rank who live on the base in Government quarters as having a highly disproportionate share of the accidents. These findings have formed the basis for a new accident control program at this military installation (*10*).

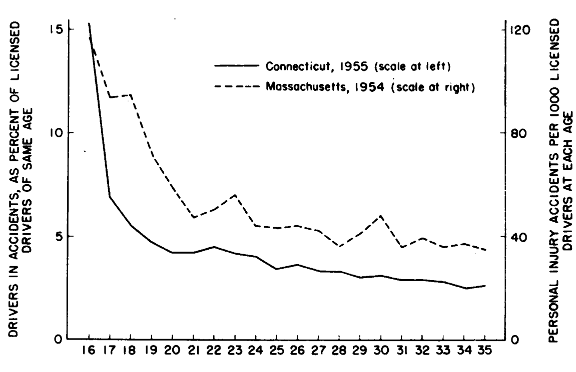
It will not be possible to present a complete analysis of the epidemiological approach in both the highway and air transport fields, and primary emphasis will be given to the findings relating to highway safety. However, there are several interesting problems in the field of air transportation which have far-reaching implications for the health and safety of large sections of the population, and a few of these will be singled out for special mention. The first one concerns the medical care of the flight crews and the handling of problem medical cases. This will be considered in the discussion of host factors. The second refers to the possibility of spreading disease by aircraft, which will be treated under the heading of host-agent factors in health and safety. The third involves host-environment relationships in connection with the transportation of patients by air, and the problems which may arise from a loss of pressure in pressurized air transports.

Host Factors in Accidents

Thus far no single characteristic of drivers has been identified which accounts for a large proportion of accidents on the highway. This is true for a variety of sensory, psychomotor, and psychological investigations (*8*, *14*). A few useful generalizations may be made, however, about driver characteristics in relation to accidents.

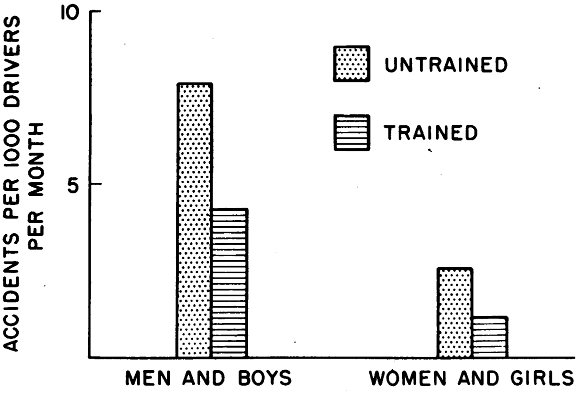
Results of a number of studies clearly indicate that, in relation to their numbers, drivers up to the age of about 25 have accidents more frequently than do those from 30 through 60 or 65 years of age. The most recent and complete information, from Massachusetts and Connecticut, indicates the highest rates for the

Figure 2. Frequency of accidents among drivers aged 16 to 35, based on Connecticut and Massachusetts experiences.



Source: References 15 and 16.

Figure 3. The safety record of trained drivers compared with that of untrained, based on 1,226 accidents during an exposure of 300,536 driver-months.



SOURCE: References 8 and 17.

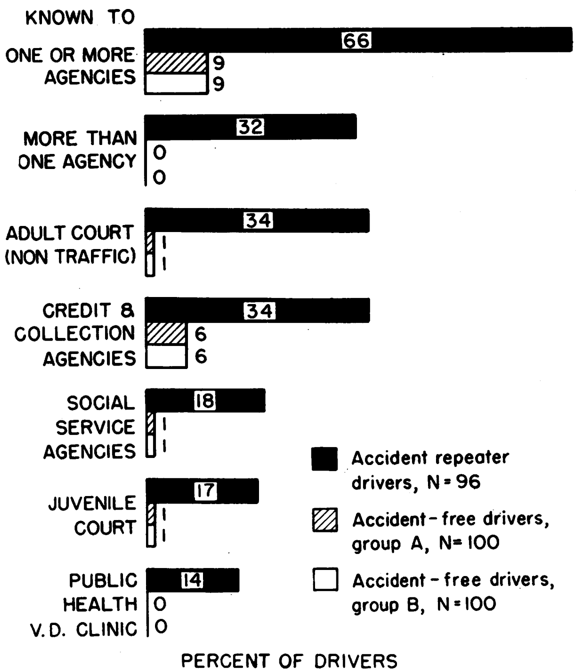
youngest drivers, those of age 16. The rate decreases with succeeding years of age, rapidly at first and then more slowly (fig. 2). It levels off at about age 30 and remains stable and relatively low through age 65 (*15*, *16*). Data related to ages above 65 are as yet too meager for interpretation. The factors responsible for the higher rates for youthful drivers are believed related to inexperience and to psychological characteristics of youth in the adolescent and early adult phases of adjustment (*8*).

In the United States, roughly 10,000, or about half, of the high schools in the country offer classroom instruction in highway safety and training in the operation of automobiles. A number of studies have been made on the effectiveness of this training. The results, shown in figure 3, agree substantially that the accident rates of trained drivers are about half as high as those of untrained, at least during the first few years of driving (*17*). Many of the reports also indicate fewer violations of traffic regulations by trained drivers. It is also apparent that classroom instruction alone is less effective than a combination of classroom instruction and behind-the-wheel training. It thus appears that the adequate initial training of drivers constitutes an important method of reducing accidents in a portion of the driving population presently characterized by the highest rates. There is still the need, however, for research on what should be taught, on ways to provide training in driving under adverse conditions and in the handling of emergency situations, and on ways to expand training programs to include all beginning drivers (*8*).

Of the greatest importance in driving safety are the attitudes and personal adjustments of drivers. A useful concept which has been developed in this area is that "a man drives as he lives." Studies of accident repeaters and accident-free drivers carried out in Canada showed that maladjustments in meeting the personal and social demands of living were far more frequent among the accident repeaters than among accident-free groups. A promising method for the identification of accident-repeater drivers resulted from this study (*18*). It was found that, as a group, the accident repeaters could be differentiated from the accident-free drivers on the basis of the number of contacts with such agencies as the civil and criminal courts, collection agencies, public health clinics, and social welfare agencies (fig. 4).

The same procedure was subsequently ap-

Figure 4. Personal and social adjustments of accident repeaters and accident-free drivers matched for geographic location and driving experience.



SOURCE: Reference 18.

plied to a large sample of truck drivers in a study at Harvard. Accident-repeater and accident-free drivers were carefully matched to meet rigid standards, and various public records were searched for their names. Findings very similar to those in the Canadian study were obtained. A statistical analysis by the chi-square technique was made to determine the relative usefulness of the various indexes of antisocial or maladjustment tendencies in differentiating those with repeated accidents from those without accidents. The relative value of selected items in discriminating between accident-free and accident-repeater drivers has been developed in the following manner:

Item	*Chi-square*
Court record of automobile offenses	7.48
Minor violation in motor vehicle records	6.76
Court record of offenses against persons	6.43
Unfavorable business inspection report	3.84
Court record of offenses against self	2.55
Court record of offenses against property	2.01

The values for the individual items having greatest significance were applied as weights to the information obtained on a new sample of unselected drivers. In this preliminary experiment the procedure identified the accident repeaters in the sample with an accuracy of 85 percent (*19*).

In another study information from the service records of 210 military pilots who had been killed in noncombat aircraft accidents was compared with records of a 20 percent sample of reserve pilots discharged after satisfactory service (personal communication). A record of disciplinary charges was found for 48 percent of the fatal accident group as against 31 percent of the control group. "Violation of flying orders" was the most discriminative type of offense—21 percent of the fatal accident group as against only 2 percent of the controls. Nonflying disciplinary infractions were also significantly different in the two groups, the accident group rating higher in resistance to order and discipline. Also noted in the accident group were the larger proportion of pilots who had not completed high school and the larger proportion of pilots who changed jobs frequently prior to enlistment.

An intensive investigation of personality factors in relation to accidents is currently being made at the University of Colorado. This approach includes extensive psychological testing and intensive psychiatric evaluation. One group test—a modified form of the Allport-Vernon Scale of Values—has provided a 70 percent accurate discrimination between no-accident drivers and those with a high-accident record. Characteristically, and in contrast with the accident-free, those drivers who have had accidents scored high on the theoretical and aesthetic scales and low on religious values. Through a combination of the test results and the clinical material, it appears that the accident-prone driver is less likely to identify himself with the father, more likely to consider authority figures unpleasant, and more likely to show an excess of regressive, masochistic fantasy. The most useful tests are now being given to all of the high school students in the city of Denver. The results will be correlated with their subsequent driving records (*10*).

In situations involving time stress and complex reactions, the lower accident rate for adult and middle-aged drivers is clear, but for persons past middle age there is some evidence that the rate may increase. It is known that reaction times tend to become longer with advancing age, and impairment in the efficiency of all the senses occurs. Many persons, however, develop compensating habits offsetting these losses. It is believed, for example, that older drivers tend to drive slower and to do less driving at night.

Research carried out at Cambridge University on the effects of aging on skilled performances has suggested the kinds of situations in which aging persons might be especially vulnerable to accidents. The implication is that when an older driver is required to assimilate a novel or complex situation instantaneously, and to carry out a rapid sequence of reactions, he is apt to become confused and make errors. Without time pressure and in familiar situations, a more adequate or efficient response can be expected (*13*, *20*).

Many accidents occur when the efficiency of the driver is impaired by some temporary condition. The efficiency and safety of driving may be adversely influenced by a variety of temporary states, although, in general, statistical proof of the importance of a given type of condition may be very difficult to obtain. For example, the role of fatigue in asleep-at-the-wheel accidents appears quite clear, but fatigue may be a more subtle factor in many other accidents. When drivers are emotionally upset or preoccupied with personal problems, alertness to the driving situation may be diminished. Alcohol is widely cited as a cause of accidents. And what may be the influence of concurrent disease or of various abnormal physical conditions? Also, is safety compromised as a result of either the direct or side effects of various drugs and remedies taken for a variety of medicinal purposes (*8, 14*)? The following are several of the findings concerning the influence of temporary conditions.

Driver fatigue is not only related to the length of time spent in driving. Consideration also must be given to such factors as amount and quality of previous rest, the nature of activities prior to driving, and concurrent emotional stress. In addition to the subtle disorganization of skill which develops with increasing fatigue, drivers when extremely tired may experience hallucinations of obstacles on the highway, and a number of accidents have been traced to actions taken by drivers to avoid collision with these imagined barriers. When interviewed confidentially, more than half of a sample of professional drivers engaged in long-trip driving admitted having had such experiences (*19*).

Driving skill is adversely influenced in many with as little alcohol in the blood as 0.03 and 0.04 percent. The likelihood of an accident increases constantly as the alcohol in the blood increases from the lowest levels (*8, 14*). The risk at 0.10 percent is estimated to be more than twice that at 0.05 percent, while the risk at 0.15 percent appears about tenfold (table 2). These data are from a recent study in Canada (*21*). Additional data from the same study (*22*) show that as the level of blood alcohol increases, there is an increase in driving errors which result in accidents. In several series of autopsies recently made on drivers killed in accidents in the United States, significant amounts of alcohol were found in the blood and brain fluids of more than half of the cases.

A physiological fact which may have special importance is that, while initially there is a close correspondence between the levels of blood alcohol and brain alcohol, the alcohol is eliminated more slowly from the fluids surrounding the brain than from the blood. Thus, elevated concentrations of alcohol may be found in the spinal fluid for some time after blood values have become negligible (*13*).

Through control of problem medical cases preventive medicine has an important role in reducing accidents on the highway and in the air. The questions of physical fitness to drive and the influence of pathological processes in accidents are of particular interest to physicians.

Most authorities would agree that epileptics, diabetics requiring insulin, and those with certain heart conditions should not operate public highway conveyances or pilot airliners because of the hazard of a sudden loss of consciousness. But what of the influence of such conditions in the general driving public and what cutoff points should be kept in mind? There are, for example, about 6 million truck drivers in the United States, yet it is known that only a small proportion of them receive thorough physical examinations, and that the development of adequate medical programs for the large number of workers in the transport industry remains to be accomplished. It would be expected that in this occupational group, a certain number use insulin, experience temporary impairments of consciousness, or have fairly advanced heart disease of one form or another (*8, 19*).

In the interest of prevention, does not the

Table 2. Accident hazard in relation to blood alcohol

Percent of alcohol in blood	Percent of accident drivers (N=432)	Percent of drivers not in accidents [1] (N=2,015)	Ratio of accident drivers to nonaccident drivers	Relative accident hazard
0.0–0.05	77. 5	91. 3	0. 85	1
0.05–0.10	7. 1	5. 4	1. 31	1. 5
0.10–0.15	4. 0	1. 9	2. 1	2. 5
0.15 and over	11. 3	1. 4	8. 1	9. 7

[1] Drivers not involved, but passing the accident scene shortly after the accident.

SOURCE: Reference 21.

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physician have a responsibility to indoctrinate the patient and the public regarding the influence of disease on driving and the effects on human behavior and efficiency of prescriptions and medications employed? Within the patient-physician relationship, must not the cardiologist, for example, estimate the likelihood of sudden loss of consciousness in various forms of heart disease and advise his patients whether it is safe to drive? In this connection, what advice should the physician give his diabetic patient? Or how is safety compromised when with advancing age changes in sensory functions and reaction time can no longer be compensated by training and experience? How can the patient-physician relationship be reconciled with the physician's responsibility for the prevention of injury when there is a question of public safety?

Unfortunately, there are few controlled experimental data available to determine precisely the role of various clinical conditions in highway safety, or to establish medical criteria and cutoff points concerning fitness to drive. Conditions involving a sudden loss of consciousness provide the most dramatic illustrations of the influence of disease in accidents. For example, in England the incidence of coronary thrombosis over a 5-year period was studied among the bus drivers of the London Transport Executive. There were 133 cases. Six prompt fatalities occurred while the driver was at the controls of a bus. Three of these resulted in accidents. In the other three attacks, the operator was able to stop the vehicle without harm (*23*).

The need for research to evaluate the influence of specific conditions in traffic accidents and to establish critical cutoff points is very great, and physicians obviously can make important contributions in this regard. The limitation on driving for persons with various illnesses or disabilities presents a serious problem. The American public, moreover, does not readily accept limitations on personal freedom. An arbitrary prohibition of driving for all those afflicted with certain conditions would be needlessly restrictive and unfair to many persons, and cooperation between the medical profession and the motor vehicle authorities in handling these problems on an individual basis is essential. Several studies have shown that drivers with quite severe physical limitations may have safe records if they are carefully supervised by their physicians. In Massachusetts, for example, a satisfactory safety record has been found with certain high-risk drivers permitted to hold licenses and drive under a program of continuing medical surveillance. These drivers include persons with such disabilities as epilepsy, diabetes, multiple sclerosis, and various amputations and paralyses (*8*).

If the problem of medical fitness to drive is to be satisfactorily worked out, large-scale studies of persons with various disabilities must be carried out to let them help decide which of this group should not drive. For example, a physiological and clinical study of 1,000 diabetics, together with statements from them about critical incidents and episodes and how they have been influenced in a dangerous way, would supply needed information in this area. Such a study might prove a more acceptable approach than the setting of arbitrary cutoff points without an experimental basis. A study of this type is at present being carried out at the Harvard School of Public Health.

In the field of air transportation, airline pilots receive periodic physical examinations through designated medical examiners of the Civil Aeronautics Administration. A few of the 80 airlines of the world have good medical departments, but less than one-fifth of the scheduled airlines have formal medical organizations. The report that each month, for a 5-month period in 1957, a pilot on active duty died while in the cockpit will emphasize the importance of continuing medical supervision, as well as of the value of having a co-pilot. One of the pressing problems in this area relates to the changing age distribution of airline pilots. With many of these men now entering age groups beyond 45 and 50, many problems of health and safety may be anticipated (*24*).

The findings for 232 problem medical cases among transport pilots have been followed through a period of 20 years. Permanent grounding resulted in only 83 cases, all of the others having returned to duty (*13*). The majority of cases were classified as neuropsychiatric and cardiovascular. Such studies are of great value in the delineation of cutoff points for airline pilots, and, furthermore, they do not support the belief held by many pilots that a serious illness necessarily results in permanent grounding.

Host-Agent Relationships

A number of findings concerning transport health and safety relate to interactions between the host and agent. In the vehicular field host-agent relationships are primarily concerned with the effective integration of the man-machine combination. In order to promote that integration, automotive equipment should be designed with regard to human capacities and limitations.

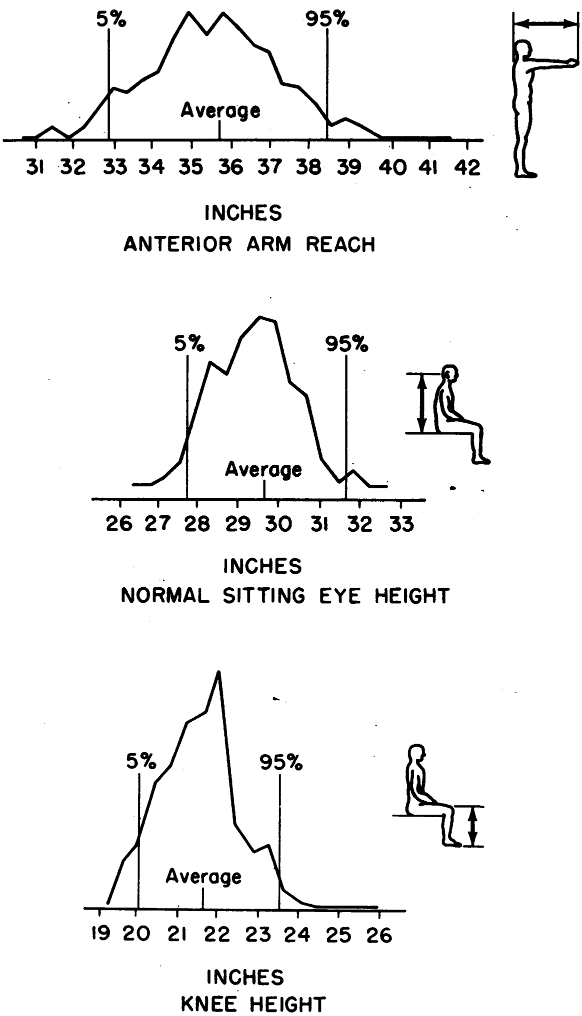
Mechanical design should be intimately related to the biological and psychological characteristics of the driver. It is reasonable to expect, therefore, that machines should be designed from the man outward, with instruments and controls considered as extensions of his nervous system and appendages. This implies that the automobile should be built around the operator, with due regard for his requirements and capacities. When this is done there should be fewer accidents and no extensive redesigning of equipment after it is put into use (*25*), but until this is done, it is hardly fair to attribute so many accidents to human failures.

In general, any control lever that is unnecessarily difficult to reach and operate, any instrument that is difficult to read, any seat that induces poor posture or discomfort, or any unnecessary obstruction to vision may contribute directly to an accident. In addition, the cumulative effects of such difficulties lead to fatigue, to the deterioration of driver efficiency, and perhaps, eventually, to an accident (*25*, *26*).

Numerous examples of faulty design in modern vehicles may be found from the standpoint of the range in body size of the drivers, the biomechanics of human movements and postures, and the characteristics and limits of human perception. A few examples are taken from a study at Harvard in which a number of current-model trucks were evaluated (*19*, *27*). A common defect was insufficient range of adjustability in the seat, either horizontally or vertically. Again, important controls were often placed too far away. For example, in one model only 5 percent of the drivers could reach and operate the handbrake from the normal driving position.

Clearances were frequently inadequate; in one model only the shortest 40 percent of drivers could get the knee under the steering wheel when raising the foot to the brake pedal. In another, this clearance was so small and the gear shift was so close to the steering wheel that the tallest 15 percent of drivers could not raise the foot to the brake pedal, by angling the knee out to the side of the wheel, without first shifting the gear lever away to the right. Figure 5 shows the distribution among truck and

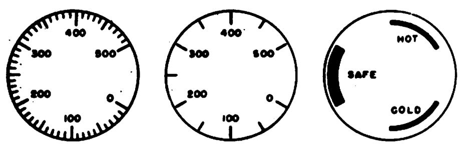
Figure 5. Variations among approximately 400 truck and bus drivers in body-size dimensions important in driving.



SOURCE: Reference 28.

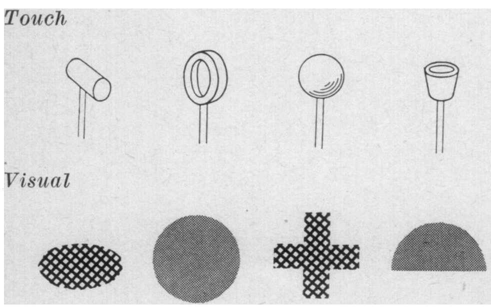
bus drivers of three body dimensions important in driving, to illustrate the kind of information that may be used in designing to "fit" the drivers (*28*).

Inadequate vision from motor vehicles constituted a common problem, especially for the perception to the side and to the rear. Within the car or truck, instruments were frequently designed or placed so that they could not be read accurately and rapidly. Knobs and switches were sometimes identical in design and could not be distinguished from each other readily. Often they were so located that they could be operated inadvertently or by mistake. For example, a driver of one make of automobile had a serious accident while traveling at high speed during the night when he inadvertently shut off his headlights with the belief that he was pushing the knob for the cigarette lighter. Many examples illustrating such errors in design are found in the reports from studies carried out by the Harvard School of Public Health (*19*, *27*, *28*).



Baker and Grether (*29*) have demonstrated visually the principle of designing dials so that they can be read accurately and rapidly. Shown are 3 dials, 2 of which require the operator to interpolate between numbers on the scale. The third gives the necessary functional information at a glance.

Examples of the way in which knobs and handles can be shape coded to prevent the inadvertent operation of controls through mistaken identity have been developed by Jenkins and Sleight (*30*). Accurate visual discrimination can also be made when there is good color or contrast with the background.



Certain design features are especially important as causes of injuries to drivers and passengers in crashes. It is recognized that the crash and impact forces of a large proportion of fatal automobile accidents were actually within the body's physiological limits of survival, if the momentum of the body had been properly checked and the forces dissipated. A large-scale study of injury in relation to the structural features of cars and the circumstances is now based on the analysis of 8,000 cases per year (*10*). This study was initiated at the Cornell Medical College by the Commission on Accidental Trauma and has received substantial additional grants from two of the major automobile manufacturers.

An early finding in this study was that being ejected from the car considerably increases the possibility of injury or death. It was estimated that a reduction of 5,000 fatalities in the United States could be achieved each year by such means as improved door latches and the use of safety belts. Based on analyses of injuries sustained by 3,450 persons in 2,000 accidents, certain structures have been incriminated as important sources of injury to vehicle occupants. In addition to door latches that open and permit ejection, they are in descending order: the steering wheel and column, the instrument panel, windshield, top edge of front-seat back, door structures, and the lower part of the back of the front seat.

Another analysis in the Cornell study indicated that speed, when lower than 50 mph, is only partially correlated with the severity of injury. At the lower speeds especially, the design features in the car and the factor of ejection are of greater importance than the rate of travel at the time of the accident.

Transportation of Diseases

Another aspect of host-agent relationships is the spread of disease by various forms of transportation. Public health authorities recognize that certain diseases can be spread just as rapidly as the fastest means of transportation. However, many of the immigration, quarantine, and health regulations were adopted in reference to surface travel, and need to be revised to keep pace with the modern airplane and the rapid transportation of persons from one part of the world to another (*1*).

The important implication of the speed of transit is that passengers can be conveyed from an infected to a noninfected area in less time than the incubation period of a disease, particularly by air transportation. Thus, infected travelers may directly expose other passengers and other persons prior to showing overt symptoms of disease, or bring a disease into an area which is free of the disease but contains a suitable vector. Also, there may be delay in proper treatment and appropriate preventive measures when the illness does become manifest because physicians in an area where it is not endemic may be unfamiliar with it (*13*).

There is also the possibility that insect vectors of disease may be carried to a noninfested area by aircraft. These insects may be merely transported and may spread disease by biting passengers during the flight. Or, escaping from aircraft after landing, they may become implanted in an area and produce new generations, creating a reservoir of infection. The possibility of transporting plant and animal diseases presents another important problem, held by some to be more serious than the threat to humans (*31*).

It had been predicted that diseases would be spread more easily with the advent of air transportation on a global basis. Thus far, however, there have been no major epidemics attributable to aviation. Contrary to the general impression, the epidemic of malaria in Natal, Brazil, in 1930 which later resulted in 100,000 cases was not introduced by aircraft. An evaluation of the time factors and the location of the original breeding sites at Natal in relation to the harbor and the airport led Soper to conclude that *Anopheles gambiae* was introduced, not by aircraft, but by the French destroyer making the mail run from Africa to Natal. Transportation by boat was also involved in the local epidemic of smallpox in the vicinity of Seattle in 1946 when a soldier returning from Japan came down with the disease while enroute and was hospitalized in that area (*13*).

Authenticated instances of the spread of disease through air transportation follow.

Toward the end of World War II, several cases of smallpox were traced directly to a wounded soldier who arrived in San Francisco on a medical evacuation plane from Korea. He had apparently contracted the disease before enplaning and symptoms were not apparent on his arrival. Subsequently, approximately 100 cases developed in other parts of the west coast.

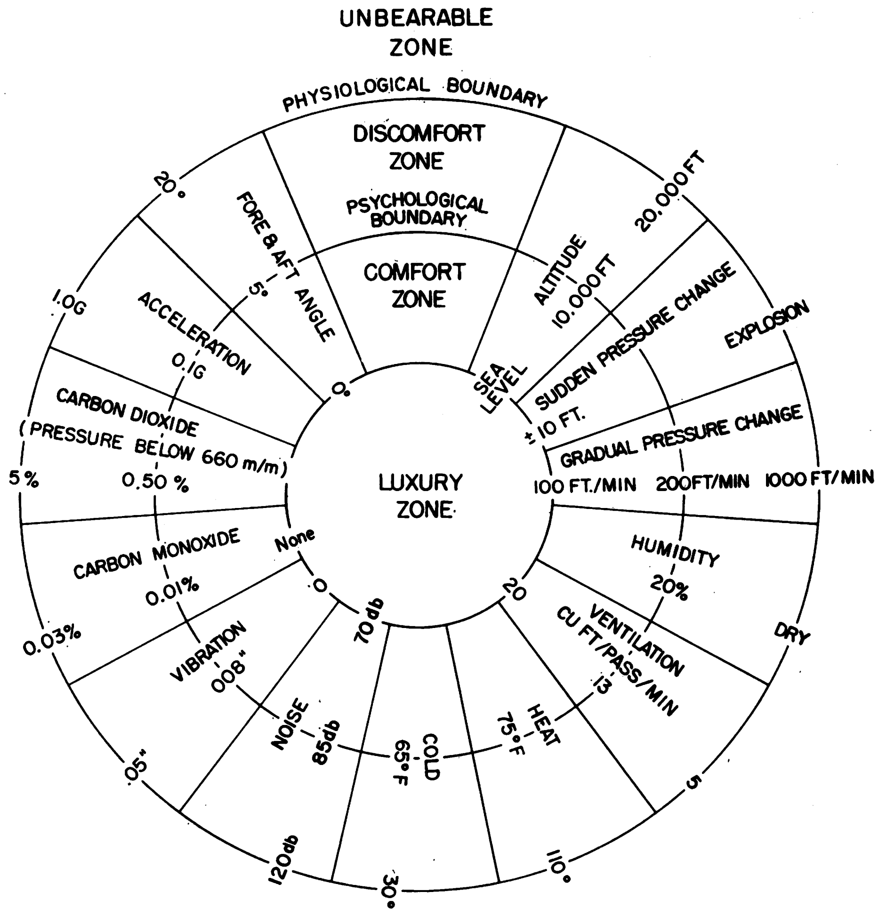
The so-called Arras epidemic of smallpox in 1946 in France was also traced to a soldier traveling by air. He had been stationed in Morocco and became ill during a flight to Italy, but he continued his journey to his home in Arras. He was not seen by a physician until 4 days had passed and was sent to a hospital with a diagnosis of chickenpox. Three days later the case was recognized to be smallpox, and in spite of revaccination of all known contacts a small epidemic followed, resulting in at least 1 death.

Another illustration concerns an outbreak of dengue fever in the Waikiki district of Honolulu in 1943. Several transport fliers arriving from the South Pacific had occupied an apartment in a Waikiki roominghouse. They had come through Suva in the Fiji Islands during an epidemic of dengue fever. Subsequently, the maids at this roominghouse became ill, and within a few weeks the Waikiki district became such a focus of infection that it was closed to military personnel until steps had been taken to virtually eliminate *Aedes* from the area.

An illustration of a potential epidemic is afforded by the case of a flight engineer who arrived in the eastern part of the United States 8 or 9 days after leaving a malarial area in Asia. He became ill shortly after arrival and was attended by a private physician who failed to recognize the disease, perhaps because of unfamiliarity with malaria. Two days later the airline's medical officer learned of the illness and had the patient hospitalized. Positive malarial smears were obtained, and despite intensive medical efforts the patient died from an overwhelming parasitemia of falciparum malaria approximately 13 or 14 days after infection. One may wonder how many more cases of malaria might have resulted if the appropriate mosquito vector, which is widespread in this country, had fed upon the patient (*13*).

The success of immunization procedures,

Figure 6. Comfort and tolerance limits for physical variables of the environment.



SOURCE: Reference 13.

modern methods for the disinsectization of aircraft, and other public health measures are responsible for holding the spread of disease to a very low incidence in air transportation. With these precautions it is possible that the threat of quarantinable and insectborne disease through air and surface transportation is of less importance to public health than such diseases as influenza and other virus infections. The proximity of passengers in closely confined quarters of an airplane cabin, bus, or railway car, especially when the air is recirculated, would facilitate the spread of airborne infections.

Host-Environment Relationships in Accidents

Many factors in the environment may influence the efficiency and safety of the operators of vehicles. Illumination, bad weather, and toxic agents such as carbon monoxide are important in highway safety, while temperature, humidity, and ventilation are significant under extreme conditions. Noise and vibration are known to be excessive in certain types of highway vehicles. In aviation, the development of the pressurized cabin is of special interest since it affords an unusual illustration of the relationships between the host, the agent, and environmental factors affecting both health and safety.

Limits have been worked out for many of the environmental variables to show their influence on those who fly in air transports in terms of zones of comfort, discomfort, physiological harm, or intolerability. These are given schematically in figure 6. If the values in the innermost of the three concentric circles are adhered to, perfect comfort is assured. The second circle represents maximum limits for comfort; hence if these values are exceeded discomfort will result. The outer circle presents values which would be physiologically harmful to the individual if they were reached or exceeded. While the chart has the advantage of brevity and clarity, it may be misleading if the values are accepted too rigidly, for many of them are interdependent. A comfort limit for noise, for example, is apt to be meaningless unless it is related to both frequency and duration. Similarly, the annoying features of vibration are functions of both the displacement amplitude and the frequency. The limits shown for carbon monoxide will be too high if persons are engaged in physical activity or are exposed to the gas while at high altitude (*13*, *31*).

Efficiency of Vision

A significant factor in host-environment relationships is efficiency of vision. In the United States, accident rates per unit of travel are three times higher at night than during the day (*7*). Presumably, this is due partly to the lower visibility provided by night-time illumination, a contention supported by lower accident rates on lighted highways and by the reduction in rates following improvement of illumination on particular highways.

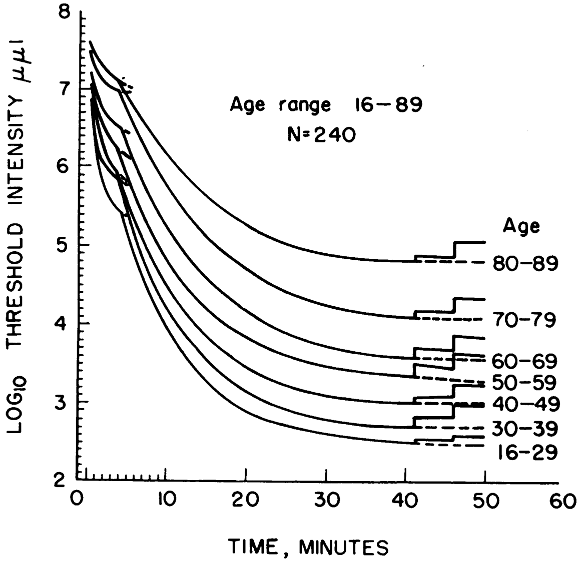
Older drivers are especially vulnerable in this connection, since the ability to see at low levels of illumination decreases regularly with increasing age. This effect is quite noticeable by middle age and becomes very marked in the elderly. We have calculated that for a dim light or object to be just seen by an eye in the dark, the illumination must be doubled for every increase of 13 years in age (*32*).

The use of tinted windshields by older drivers may present special hazards at night, since the glass further reduces visibility by reducing the intensity of light reaching the eye (*10*, *32*). Figure 7 shows the increase in light for threshold perception as age increases. Slightly more intensity was needed at all ages when test lights were seen through ordinary clear windshield glass, which here is introduced at 41 minutes. When tinted glass is used, a larger increase in intensity is required. This illustrates in quantitative terms the importance of the interrelationship between factors relating to the host, the agent, and the environment.

Toxic Agents in the Environment

Exposure to subclinical concentrations of carbon monoxide frequently leads to effects which may not be noticed by drivers. Even very small amounts of this gas breathed into the lungs are taken into the blood stream, resulting in some degree of oxygen deficiency in the tissues. Early symptoms are lowered alertness, difficulty in concentration, slight muscular incoordination, and a mental and physical lethargy. Reduction of night vision can be demonstrated as one of the first effects (*13*). These initial symptoms are not permanently injurious, but owing to their nature, they may easily cause hazardous situations. Although, in general, exhaust systems have been improved to prevent the leakage of fumes, appreciable

Figure 7. A comparison of the average dark adaptation curves for eight age groups, each curve indicating the greater sensitivity of the retina as it becomes adapted to darkness.



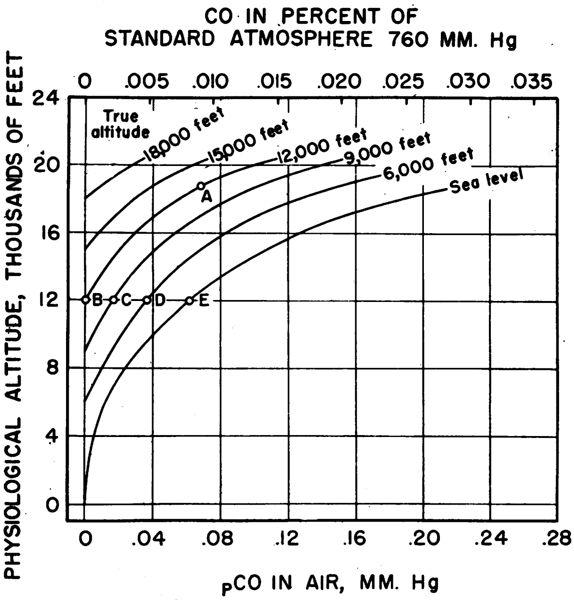
SOURCE: References 10 and 32.

NOTE: The first 4 or 5 minutes are concerned with cone vision; the remainder of the curve shows the adaptation of the rods. The vertical separation of the curves indicates the increase in intensity of light required for threshold perception (scale at left) as a function of increasing age. Also shown are the slight increase in intensity required when lights are viewed through clear windshield glass (at 41 minutes) and the relatively large increase in illumination needed when tinted windshield glass is placed before the dark-adapted eye (46 minutes). The latter effect may be somewhat more pronounced in the older groups.

concentrations of this gas have been found in the passenger compartment when the car stands with motor idling or moves slowly in dense traffic. Drivers should be well indoctrinated on the need for flushing vehicles with fresh air in such circumstances.

In addition, drivers and airmen should know that certain conditions will intensify the effect of carbon monoxide from engine exhaust (*13*). For example, the effect of carbon monoxide is obviously more pronounced the higher the altitude. If the blood of a chronic smoker at sea level already contains 5 to 7 percent carbon monoxide absorbed from tobacco smoke, he is affected as if he were a nonsmoker at an altitude of 7,000 or 8,000 feet. Figure 8 shows the combined effect of carbon monoxide and altitude as expressed in terms of the altitude producing an equivalent degree of anoxia. Thus, a person at sea level exposed to air with a partial pressure of 0.06 carbon monoxide would be affected to the same extent as if he were breathing uncontaminated air at 12,000 feet (*31*). If other oxygenation-reducing factors are present, such as the use of alcohol or certain medicines (sulfanilamide, barbiturate, or acetanilid, for example), the various factors may combine in their effects, resulting in a significant state of oxygen deficiency seriously jeopardizing safety (*8*).

Figure 8. The combined effect of carbon monoxide and altitude expressed as altitude producing an equivalent degree of anoxia.



SOURCE: Reference 31.

Air Transportation of Patients

Patients are using air travel more and more because they can be transported to treatment and surgical centers rapidly.

The Flying Doctors Service of Australia, inaugurated in 1928, clearly demonstrated that the airplane provides an unusually effective way of transporting patients. During World War II the advantage of air travel for the sick and injured was dramatically demonstrated. Only 46 deaths occurred in flight in approximately 1,260,000 patient flights by the U. S. Air Force from all military theaters in the period January 1943 to April 1947.

A study has been made of the passenger deaths in the scheduled airlines of this country from 1930 to 1956. An extremely low rate, less than 1 death per million revenue passengers, has been found consistently. In 1955, for example, there were 22 in-flight deaths in 38 million revenue passengers, or a rate of 0.6 per million (*13*). Instances of loss of consciousness in flight (table 3) have also been found to be infrequent in comparison with the volume of traffic (*33*).

The chief precautionary measures for patients undertaking travel by air relate to (*a*) possible interference with the availability of oxygen and (*b*) the mechanical effects of the expansion of internal gases. If a physician understands the basic physiological principles involved, appropriate decisions can be made in regard to the advisability of air travel by individual patients (*13*).

Certain conditions may be characterized by a lowered oxygen saturation of the blood, or a limitation on the transport or utilization of oxygen when the body is placed under stress. Flight may thus be contraindicated or undertaken with caution by patients with certain forms of cardiovascular disease, pulmonary disease, anemia, diabetes, and overwhelming infections or shock, because of additional hypoxia due to altitude.

Among patients with cardiovascular diseases, flight may most frequently be contraindicated for those having limited cardiac reserve, or re-

Table 3. Instances of unconsciousness during flight in United States scheduled airlines, 1947–55, by associated condition and altitude

Associated condition	Persons losing consciousness	Altitude (unpressurized flight)		Cabin pressurized	Altitude or pressurization unknown
		0–8,000 feet	Above 8,000 feet		
Cardiovascular disease	80	19	25	22	14
Epilepsy, seizures, and convulsions	75	16	14	29	16
Fatigue	42	8	10	16	8
Motion sickness	41	23	2	9	7
Apparent hypoxia	17	2	9	[1] 6	0
Other and unknown	492	112	114	170	96
Total	747	180	174	252	141

[1] Includes 4 instances following accidental decompression.

SOURCE: Reference 33.

cent myocardial infarction. Such patients are already under stress to compensate for an insufficient supply of oxygen in heart muscle or are receiving only a marginal supply of oxygenated blood through the general circulation. Experience has shown, however, that altitude is probably not a critical factor for the cardiac patient unless either the disease or the exposure is severe. While those with a history of severe valvular disease, recent coronary thrombosis, or easily provoked angina probably should not fly, individuals with well-compensated heart diseases need not hesitate to fly at moderate altitudes, particularly if cabins are pressurized to about 6,000 feet, or if oxygen is available at all altitudes.

In some pulmonary conditions such as pneumonia, emphysema, and severe asthma, there may be preexisting oxygen want due to mechanical interference with the diffusion of oxygen into the blood in the lungs. In bronchial asthma there may also be oxygen want due to spasm of the smooth muscles of the finer bronchioles. With respiratory embarrassment as well, the individual severely ill with this condition will be unable to cope with the additional hypoxia of even moderate altitudes. The average asthmatic without emphysema, however, is not likely to be affected adversely by altitude.

Serious consequences may result if an anemic person flies at high altitude, and a patient with anemia of even moderate degree might be expected to react poorly to hypoxia because of the impairment in the oxygen transport system of the blood. Transfusion before flight would be required by many with anemia or leukemia, and oxygen should be supplied from the ground up to patients with those conditions.

Air travel is not contraindicated for diabetics who are fully stabilized and can follow their time schedules for insulin and meals conscientiously. Difficulties may arise from either insulin reaction or diabetic coma. The effects of oxygen want are greatly accentuated when accompanied by low blood sugar, and the reaction may be more severe if fluid and food are lost by the patient because of air sickness.

Certain upper respiratory and thoracic abnormities and abdominal and neurological conditions may be adversely influenced by the mechanical effects of the expansion of internal gases incident to the decreased barometric pressure at high altitude.

Sinus or otic barotrauma may result in persons with upper respiratory or middle ear disorders since such patients may experience difficulty in equalizing internal and external pressures, particularly during descents. If it is necessary to fly during an acute inflammatory phase, the use of vasoconstrictor drugs is indicated to secure adequate ventilation of the sinuses and middle ear to prevent damage and spread of infection.

One of the most serious contraindications to flight is the presence of pneumothorax. Several deaths in air travel have been traced to the expansion of a large amount of encapsulated air in pneumothorax patients. If there is free air in the thoracic cavity, the expansion of this air may not only collapse the lung but may also displace the mediastinum, affecting other organs. Tidal air volume is also reduced. The various factors that affect the maximum safe altitude must be calculated for each person on each occasion when he travels. If flight is necessary, it is unwise to start immediately after a refill, and it may be advisable to aspirate the air from the pleural cavity to compensate for the decreased atmospheric pressure during flight.

The expansion of gases trapped in viscera and the abdominal cavity is the basis for contraindicating air travel for about 10 days after persons have undergone extensive abdominal surgery. Intestinal obstruction from any cause presents a serious problem, and if a patient must be transported, procedures to reduce accumulated gases should be followed. Perforated ulcer of the stomach and perforation of the bowel are other conditions that would contraindicate flight at any but low altitudes.

While the hazards of air travel in regard to neurological ailments have been least well defined, difficulties might be expected in patients (*a*) with air injected for diagnostic purposes, (*b*) with cranial injuries such that there may be herniation of the brain through openings in the skull, and (*c*) with conditions in which there may be an increase in intracranial or intraspinal pressures. Marked decreases in atmospheric pressure might be expected to affect such patients adversely. Experience suggests that routine flying as a passenger is not contraindicated for the epileptic whose seizures are controlled by drugs, and there is little indication that blood changes encountered in flight up to 10,000 to 12,000 feet are sufficient to induce seizures.

Effects of Loss of Pressure in Flight

After a sudden decompression at high altitude, passengers would be exposed to severe cold, and a few might develop "bends" if the plane were unable to descend to low altitude within a short time. The low tension of oxygen in the air at high altitude, however, is a limiting factor with the far more serious implications of acute oxygen want. At 40,000 feet, for example, useful consciousness is retained for only 30 to 40 seconds. Even at 25,000 feet most persons would lose consciousness if exposed for 1½ to 2½ minutes unless supplementary oxygen were available (*13*).

Rapid decompressions have occurred in civil air transportation of the United States at a rate of about 1 incident in 100,000 hours of flying. Fortunately, most of these incidents so far have occurred below 25,000 feet, and planes have been able to descend to low altitudes immediately in almost all instances. In several it was necessary to provide oxygen to passengers showing signs of distress, and at least four instances of loss of consciousness have been reported. It is obvious that a decompression at 40,000 feet would present a very serious problem, and additional precautions will be necessary in the new jet transport equipment designed to operate at 35,000 to 40,000 feet. Unless cabin structures and pressurization are made completely foolproof and as reliable as any major component of the aircraft, it will be necessary to carry emergency oxygen equipment for all on board (*34*).

Conclusions

Accidents now rank above disease as the chief cause of death and disability to many segments of our population, and now constitute a major threat to the well-being and health of our people.

The accepted function of medicine has been the treatment of disease and injury. Just as the province of medicine has been extended to include the prevention of disease, it is proposed that the prevention of accidental trauma should be a responsibility of preventive medicine and public health.

When accidental trauma is considered a noncontagious mass disease of epidemic proportions, the epidemiological approach should be applied to the study and control of injuries since similar biological principles are involved. An interdisciplinary approach is a basic requirement in this because multiple causation is found in most accidents.

The causes of accidents may be identified in the interactions between the host, the agent (or equipment), and variables of the environment. Human factors are especially important, and the physician can contribute effectively in the analysis of accident causes because of his background in the biological sciences and his knowledge of human behavior. He can indoctrinate his patients and teach while treating.

Factors of significance to the host in the control of accidental trauma include not only those which determine suitability for a given task such as driving a vehicle or piloting a plane, but also such factors as age, training, and, particularly, personal adjustments. The most promising approach to identifying the accident repeater is based on the concept that "a man works, or drives, as he lives."

The control of various temporary host factors such as fatigue, emotional problems, effects of alcohol, and the influence of disease is highly important. Periodic medical examinations and adequate programs of health maintenance can play a signficant role in improving safety both in land and air transportation.

Biotechnology and human engineering should be applied to the design of equipment in order to achieve a closer integration between the operator and his equipment.

The agent of disease also is significant in modern transportation, since insect vectors of disease might be transported in planes and other vehicles and since long journeys may now be completed within the incubation period of most contagious diseases. A review of epidemics attributable to transportation indicates that thus far the spread of disease through air transportation has been less than predicted but that the constant threat to public health must be continually controlled.

Host-environment relationships also have implications for safety in transportation because of the influence upon the individual of physical variables such as the level of illumination, the temperature and humidity, and exposure to carbon monoxide and other toxic agents. Data have been worked out for each of these variables outlining the zones of comfort and discomfort and the ranges where human performance is adversely influenced.

In air transportation, the low tension of oxygen at high altitudes and decrease in barometric pressure with altitude are significant not only for their influence on the performance of airmen, but also because of their implications for the safety of travel by air by persons who are physically unfit or who are afflicted with certain diseases or physical conditions. These same factors are of critical importance in the development of equipment to transport passengers at very high altitudes because of their significance in the case of a sudden loss of pressurization.

In conclusion, the physician or the public health officer has a direct responsibility for the prevention of accidental trauma. He may contribute most effectively by his aid in carrying out controlled experimental and clinical studies, epidemiological surveys, and by collaborating with specialists in other biological sciences, engineers, and administrative officers in a combined approach to this problem.

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